

3-METER KA-BAND INFLATABLE MICROSTRIP REFLECTARRAY

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INTRODUCTION

In order to meet the increasingly stringent budget constraints for space missions, the National Aeronautics and Space Administration (NASA) is currently developing lightweight spacecrafts with reduced stowed volume but with increased capabilities. Even though smaller spacecraft can be built due to recent advances in electronics and micro-devices, JPL/NASA's Earth remote sensing and deep-space exploration programs have increasing demand for spacecraft high-gain and large aperture antennas. Additionally, we need to consider that new missions are looking at faster communication data rates and thus higher frequencies such as Ka-band (34 GHz) are required. To meet these goals, large-aperture antennas need to be deployable and breakthrough, high pay-off concepts need to be developed.

One deployable concept using an inflatable parabolic reflector [1] was introduced about two decades ago and was demonstrated in a recent space shuttle experiment [2]. However, the full implementation of this concept is still hampered by the inability to achieve the required surface accuracy. Even with the development of technology for rigidizable membranes and inflatable tubes, it is believed that it will be difficult to maintain the desired surface accuracy of a large curved parabolic aperture for the long duration of a mission.

To mitigate the problems with curve surfaces, a new class of planar array technology is being studied and developed at JPL [3,4]. A flat surface is a more "natural" shape for space environment and thus it is significantly simpler to maintain the required surface tolerance on a planar array, than trying to do it on a curved "non-natural" surface, such as a parabolic reflector. In addition, a planar array offers the possibility of wide-angle beam scanning, which cannot be easily achieved with a parabolic reflector.

At JPL, a 3m-diameter Ka-band inflatable microstrip reflectarray [5] for deep-space telecom applications has recently been developed. The RF design and the aperture membrane surface of this antenna was developed at JPL, while the development of the inflatable structures and the antenna integration were accomplished jointly by JPL and its partner, ILC Dover, Inc.

KA-BAND INFLATABLE REFLECTARRAY CONCEPT

Inflatable structures are deployed in a flexible state and with the introduction of inflation gas and the assistance of controlled deployment mechanisms, the structure is able to provide a frame from which an antenna or radar membrane can be suspended and tensioned. Based on these principles, a 3m-diameter inflatable reflectarray concept was developed. Figure 1 shows the stowed and fully deployed configurations of the Ka-band inflatable reflectarray concept.

Mechanical Characteristics

The 3 m inflatable Ka-band reflectarray consists of a horse-shoe shaped inflatable tube that supports and tensions the 3-m aperture membrane. The tube, 25 cm in diameter, is made of urethane coated Kevlar and is inflated to 3.0 psi pressure, which translates to about 90 psi of tension force to the aperture membrane. The inflatable tube is connected to the aperture membrane at 16 catenary points with spring-loaded tension cords. Each connecting point has displacement adjustment capability in the x, y, z directions so that the circumference of the circular aperture membrane can be made into a single plane orthogonal to the feed horn axis. The single-layer aperture membrane is a 5-mil (0.13 mm) thick

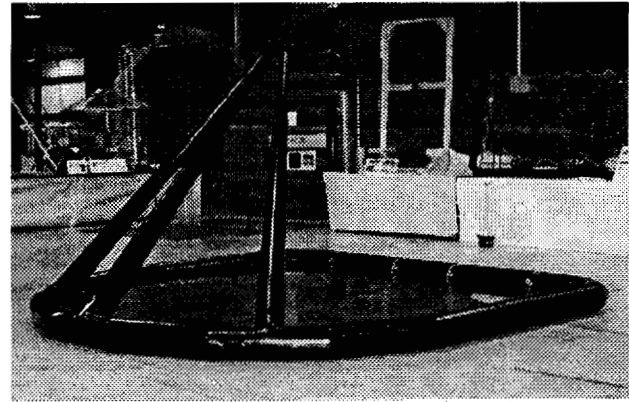
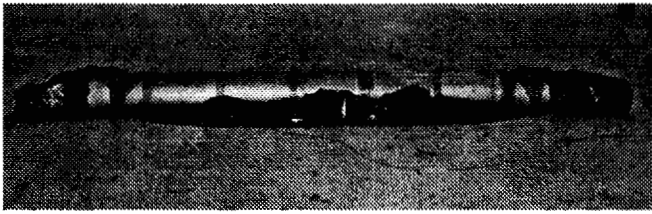
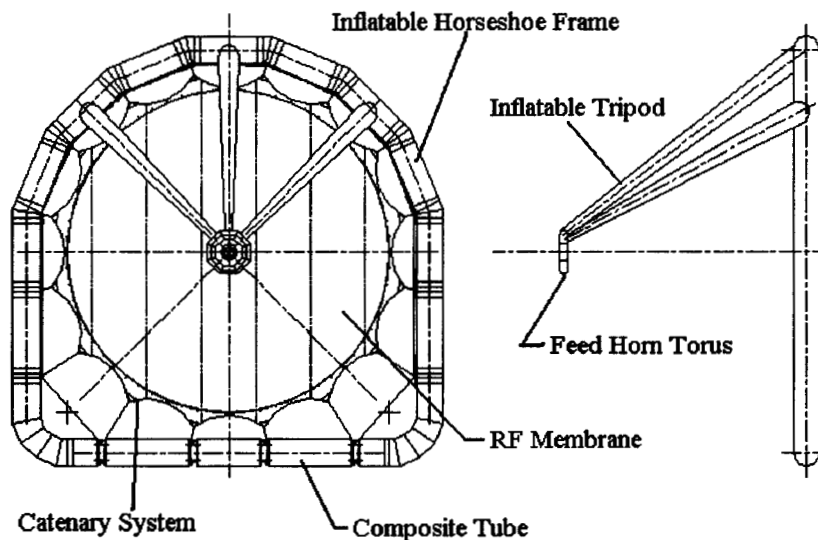


Figure 1. Stowed and Deployed Configuration of Inflatable Reflectarray

Uplex™ dielectric material (a brand of polyimide) with both sides clad with 5-micron thick copper. The copper on one side was etched to form approximately 200,000 microstrip patch elements, while the copper on the other side is unetched and serves as the ground plane for the patch elements. The inflatable tripod tubes, asymmetrically located on the top portion of the horse-shoe structure, are used to support a Ka-band corrugated feed horn. The horse-shoe-shaped main tube structure and the asymmetrically connected tripod tubes are uniquely designed in geometry to avoid membrane damage and flatness deviation when the deflated antenna structure is rolled up. Figure 2 shows a picture of the major components of the reflectarray.



A measuring device consisting of a trammel arm and a caliper was designed to measure the flatness of the membrane. The membrane RMS was measured to be 0.016 mm with a maximum flatness deviation of ± 0.3 mm. The design requirements were 0.5 mm for RMS and 0.8 mm for peak flatness.

The entire system, excluding inflation system, feed and cables, has a total mass of 12.88 kg which translates into a mass per unit of aperture area of 1.82 kg/m^2 . The stowed volume is a cylindrical roll of 4 m long by 30 cm in diameter.

Test and Results

The antenna's RF tests were performed at the in-door compact range of Composite Optics, Inc. (COI). A typical elevation pattern of the antenna is given in Fig. 3 where a 0.22° narrow beam was measured. The sidelobe is -30 dB or lower below the main beam peak, and the cross-pol level is -40 dB or lower. All patch elements are circularly polarized and are identical in dimensions. Their angular rotations [6] are different and are designed to provide correct phase delays to achieve a co-phased far-field radiation. The antenna gain was measured versus frequency. The results show that the antenna is tuned at the desired frequency of 32.0 GHz with a -3 dB bandwidth of 700 MHz. A peak gain of 50 dBic was measured and is significantly lower than the expected value of 56 dBic. This measured gain indicates an aperture efficiency of only 10% which is far from the expected 40% . This unexpected low efficiency was the result of a design flaw. The phase delay lines that attached to each patch element have very poor impedance match to the patch and, thus, cause poor radiation efficiency. A second iteration development has been initiated to correct this design flaw. Although the aperture efficiency was poor, the achievement of excellent membrane flatness indicating that inflatable array antenna at Ka-band is now feasible.

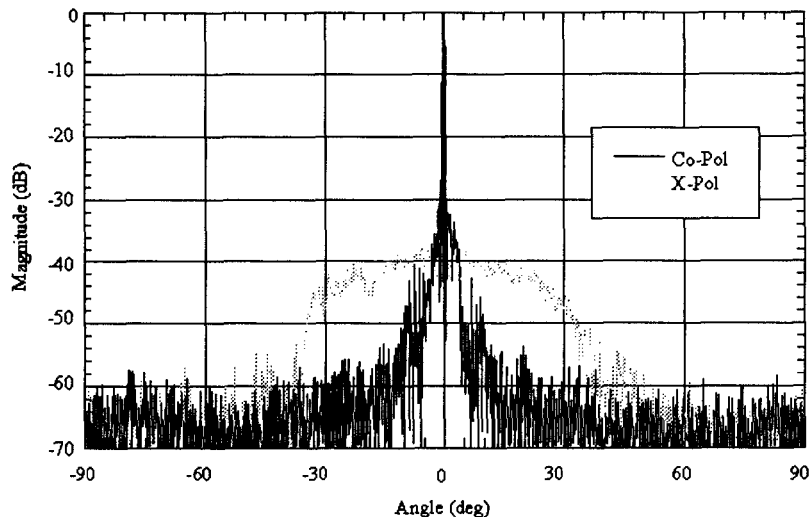


Figure 3. Inflatable Reflectarray Test Results

FUTURE CHALLENGES

To successfully develop an inflatable array antenna at any frequency throughout the microwave and millimeter-wave spectrums and with any aperture size from several meters to tens of meters, several technical challenges must be addressed and resolved. These challenges include:

- Membrane flatness and separation
- Tube rigidization
- Controlled deployment
- Packaging efficiency and launch restraint design
- Membrane mountable electronic components
- Modeling and simulation of static and dynamic space environmental effects

CONCLUDING REMARKS

The 3-meter Ka-band inflatable reflectarray antenna concept was developed to demonstrate that the inflatable array technology is feasible in reducing the mass and stowage volume of future spacecraft's high-gain and large-aperture antennas. To realize the inflatable array technology for space application, several challenges in the mechanical area remain to be resolved and will be addressed in future work. Additional work is also necessary in the RF area to optimize the antenna patch configuration in order to obtain better efficiencies. The development of inflatable structure rigidization methods, controlled deployment techniques, space survivable membrane materials, and accurate mathematical structure analysis tools are inevitable.

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